# Impacts of soil compaction and tree stump removal on soil properties and outplanted seedlings in northern Idaho, USA

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Page-Dumroese, D. S., Harvey, A. E., Jurgensen, M. F. and Amaranthus, M. P. 1998. **Impacts of soil compaction and tree stump removal on soil properties and outplanted seedlings in northern Idaho, USA**. Can. J. Soil Sci. **78**: 29–34. Intensive timber harvesting and site preparation are becoming more common as demand for timber-based products increases. On some harvested sites in the western United Staes of America and Canada, stump removal is used to ameliorate root disease problems. Soil compaction and nutrient loss could become a problem on some sites after harvesting, site preparation, or stump removal. In a non-replicated, randomized block experiment, two levels of soil compaction (none and severe) and a stump extraction treatment were examined on an ash-cap soil in northern Idaho. These treatments were planted with Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco) and western white pine (*Pinus monticola* Dougl. ex D. Don) seedlings. Soil compaction increased post-harvest bulk density 15–20% to a depth of 30 cm. Stump removal decreased surface soil bulk density, but it increased at the 30- to 45-cm depth to levels equal to the soil compaction treatment. One year after outplanting, seedling top weights were similar among treatments, but root volume was significantly reduced in the soil compaction treatment. Soil compaction and stump removal treatments also reduced the numbers and morphological types of ectomycorrhizae and non-ectomycorrhizal short roots on Douglas-fir. Western white pine seedlings had reduced numbers of non-ectomycorrhizal short roots in the same treatments. Three years after outplanting, stump removal resulted in smaller root collar diameters and less total N content for both seedling species. Severe site disturbance, with associated soil compaction and mixing, may decrease productivity of ash-cap sites by reducing pore space and root and ectomycorrhizal activity. Managers must weigh short-term benefits of intensive site disturbance with possible long-term loss of soil productivity.

**Key words:** Bulk density, compaction, ectomycorrhizae, stumping, site preparation, Douglas-fir, western white pine

Page-Dumroese, D. S., Harvey, A. E., Jurgensen, M. F. et Amaranthus, M. P. 1998. **Incidences du compactage du sol et de l'essouchage sur les propriétés du sol ainsi que sur les jeunes plants mis en place en pleine terre dans le nord de l'Idaho aux États-Unis**. Can. J.Soil Sci. **78**: 29–34. Les pratiques intensives d'exploitation du bois d'oeuvre et de préparation du terrain se répandent de plus en plus en réponse à la demande croissante pour le bois de construction. À certains emplacements forestiers de l'ouest des États-Unis et du Canada on a recours à l'essouchage comme moyen d'atténuer les problèmes de pourridié. La compaction du sol et les pertes en éléments nutritifs pourraient causer des ennuis à certains emplacement par suite des pratiques d'abattage, de préparation du terrain ou d'essouchage. Dans une expérience conduite en blocs aléatoires non répétées, nous avons examiné les effets de deux niveaux de compaction, nul ou grave et d'un traitement d'essouchage sur un sol à horizon superficiel de cendre volcanique du nord de l'Idaho. Les parcelles étaient plantées en semis de sapin de Douglas (*Pseudotsuga menziesii* var *glauca* (Beissn.) Franco) et de pin blanc de l'Ouest (*Pinus monticola* Dougl. ex D. Don). Le compactage accroissait de 15 à 20 % la densité apparente après récolte jusqu'à une profondeur de 30 cm. L'essouchage abaissait la densité apparente de la couche de surface mais, à la profondeur de 30 à 45 cm, on observait un accroissement comparable à celui causé par la compaction. Une année après la mise en place des semis, le poids des parties aériennes était le même d'un traitement à l'autre mais le volume racinaire était significativement moins important dans le traitement de compaction. En outre la compaction et l'essouchage réduisaient les quantités et les variantes morphologiques des racines courtes à ectomycorhizes et sans ectomycorhizes du sapin de Douglas. Ces mêmes traitements diminuaient également le nombre de racines latérales courtes sans ectomycorhizes chez le pin blanc de l'Ouest. Trois ans après l'installation des plants en pleine terre, l'essouchage se traduisait chez les deux essences par un plus petit diamètre du collet et par une moindre teneur en N total. Une grave perturbation du terrain, avec la compaction et le mélange des matériaux qui en découlent, peut abaisser la productivité des sols à horizon superficiel volcanique en réduisant la porosité ainsi que l'activité des racines et des ectomycorhizes. Les gestionnaires forestiers doivent peser les avantages à court terme des perturbations violentes du terrain en regard des pertes éventuelles de longue durée qu'elles peuvent entraîner pour la productivité du sol.

**Mots clés:** densité apparente, compaction, ectomycorhizes, essouchage, préparation du terrain, sapin de Douglas, pin blanc de l'Ouest

Northern Idaho forests have relatively high levels of productivity. Volcanic ash-cap soils, with an inherently low bulk density, high porosity, and low shear strength are important contributors to this high productivity (Geist and Cochran 1991; Davis 1992). However, ash-cap soils are cohesionless and prone to both vibrational and compressional compaction (Cullen et al. 1991). Compaction recovery of these soils after harvesting or site preparation is minimal, with compaction at 10- to 15-cm depths persisting for at least 20–35 yr (Froehlich et al. 1985; Geist et al. 1989). Seedlings growing on compacted ash-cap soils were smaller 45 yr after outplanting as compared with non-compacted controls (Froehlich et al. 1985).

Harvesting and mechanical site preparation activities displace, mix, compact, and remove surface mineral horizons (Jurgensen et al. 1997). Increasingly, stump removal is also being used as a form of mechanical site preparation in the western United States of America and Canada to control the spread of *Armillaria* root disease before planting (Morrison 1981; Thies 1984; Wass and Smith 1997). Stump extraction has been conducted on several thousand hectares in British Columbia and the United Styates of America over the past 15 yr (Smith and Wass 1991). While stump removal apparently reduces root disease incidence in regeneration (Bloomberg and Reynolds 1988; Morrison et al. 1988), concern has surfaced about potential short-term soil damage (Smith 1981; Thies 1984), and more importantly, long-term soil productivity.

Sustaining soil productivity involves understanding interactions among soil, roots, seedlings, and ectomycorrhizae. Compaction and stump removal may reduce pore space and impede water, oxygen and carbon dioxide movement through the soil (Conlin and van den Driessche 1996), root penetration to lower horizons, and development of ectomycorrhizal fungi (Amaranthus and Perry 1989a; Amaranthus et al. 1996; Harvey et al. 1996), all of which could greatly reduce tree water and nutrient uptake. Consequently, this study was conducted to determine the impact of removing stumps and soil compaction on soil properties, ectomycorrhizal and root development, and tree seedling growth on a representative ash-cap soil in northern Idaho. This study is part of the USDA, Forest Service's National Long-Term Soil Productivity Project (Powers et al. 1990).

## MATERIALS AND METHODS

### Site Description

This study was conducted on a bench adjoining the Priest River at the Priest River Experimental Forest in northern Idaho (latitude 48°21′N, longitude 116°50′W), elevation 725 m. The study site receives about 83.8 cm of precipitation annually, 80% as snow, with a mean annual temperature of 6.6°C (Wellner 1976). Before harvest the site consisted of a well-stocked stand dominated by ca. 90-yr-old western white pine, western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), Douglas-fir, and western larch (*Larix occidentalis* Nutt.). Habitat type is classified as *Tsuga heterophylla*/ *Clintonia uniflora* (Cooper et al. 1991).

The soil is a medial, frigid Ochreptic Fragixeralf (Soil Survey Staff 1996) with a silt loam surface layer 28 to 38 cm thick, derived from Mount Mazama volcanic ash. The subsoil is a silty clay loam derived from glacial lacustrine (lake) sediments approximately 50 to 75 cm thick, underlain at depths of 60 to 100 cm by gravelly to very gravelly sands and sandy loams deposited by alluvial processes.

### Plot Layout and Treatments

The study site was divided into three 0.8-ha plots surrounded by a 200 m buffer. In 1990, trees were directionally felled and skidded along a central skid trail or from plot boundaries to prevent compaction during harvesting. Trees were harvested to an 8-cm top and tops and branches remained on the soil surface after harvesting. The no compaction treatment was left undisturbed after harvest. Surface organic material was removed from the soil compaction treatment during the first of four passes of a D-6 Caterpillar tractor to minimize mixing of organic matter and mineral soil. All removed organic matter was then replaced back onto the plot. Gravimetric soil moisture content was measured at 16 grid points in each plot during compaction and averaged 25%. In the stump removal plot, stumps >12 cm were removed by prying and lifting with a track mounted grapple skidder used during harvesting. Small stumps were pulled with a tripod mounted block and tackle placed directly over each stump with power provided by a small farm tractor. We attempted to pull every stump from the treatment plot, but were only successful about 50% of the time. The remaining stumps (in all size classes) were too well anchored to remove.

### Soil Sampling

In each 0.8-ha plot, 16 subplots were established on a 20-m grid. Each subplot in the stump removal plot contained areas disturbed by stump pulling and also had some remaining stumps. At each location, bulk density samples were taken with a 5-cm diameter core sampler (Blake and Hartge 1986) at 0- to 10-cm, 10- to 20-cm, and 20- to 30-cm depths before harvest (1990), and 1 yr (1992), and 3 yr (1994) after treatment. Site treatments were done in 1991. Bulk density cores were dried 24 h at 105°C before weighing. Soil strength readings were taken with a Rimik® CP-20 cone penetrometer to a depth of 60 cm before harvest and 1 yr after treatment at each of the grid points used for bulk density measurements. Penetrometer readings were taken within the same 24-h period to reduce moisture variation between subplots. At each subplot, three replicate penetrometer readings were taken.

### Seedling Measurements

One-year-old Douglas-fir and western white pine container grown seedlings (seven families of each species from local seed sources) were planted at a 2.5-m spacing on each 0.8-ha plot during May 1992 . Fourteen seedlings of each species were randomly collected on 14 October 1993 by trenching beyond the width and depth of the existing root system with a tile spade and shaking loose soil free. Roots were thoroughly washed, root volume measured by water displacement (Burdett 1979), and shoots and roots weighed after drying 24 h at 60°C.

On 1 June 1993 three seedlings of each species were randomly collected for ectomycorrhizae analysis from each treatment plot by trenching beyond the width and depth of the existing root system with a tile spade. Root systems of excavated seedlings were gently washed free of soil and then subsampled into three 2.5-cm-wide cross sections from upper, middle, and lower root portions (5–10 cm, 15–20 cm, and 25–30 cm below the root collar). Active tips were tallied as non-mycorrhizal (tips had root hairs, were clear/translucent or lacked hyphal mantle) or ectomycorrhizae (tips mantled by hyphae) when observed through a stereo microscope (2–5× magnification). Differentiation of ectomycorrhizae types was based on mantle structure, color, surface appearance, branching morphology, degree of swelling, length and characteristics of rhizomorphs or emanating hyphae. Morphological types found in this study are described in Amaranthus et al. (1996).

**Table 1. Mineral soil bulk densities before harvesting and 1 and 3 yr post-harvest as affected by soil compaction or stump removal**

| Site treatment | Depth (cm) | Pre-harvest | 1 yr post-harvest (Mg m$^{-3}$) | 3 yr post-harvest |
|---|---|---|---|---|
| No compaction | | | | |
| | 0–10 | 0.53*a* | 0.63*a* | 0.65*a* |
| | 10–20 | 0.68*a* | 0.76*a* | 0.79*a* |
| | 20–30 | 0.77*a* | 0.76*a* | 0.78*a* |
| Soil compaction | | | | |
| | 0–10 | 0.65*a* | 0.84*b* | 0.82*b* |
| | 10–20 | 0.75*a* | 0.85*a* | 0.89*b* |
| | 20–30 | 0.84*a* | 0.91*b* | 0.94*b* |
| Stump removal | | | | |
| | 0–10 | 0.66*a* | 0.55*a* | 0.59*a* |
| | 10–20 | 0.77*a* | 0.78*a* | 0.79*a* |
| | 20–30 | 0.80*a* | 0.91*c* | 0.87*b* |

*a–c* In each row, different letters indicate significant differences ($P \leq 0.05$) by Fisher's LSD between years.

In September 1995, 60 randomly selected 3-yr-old seedlings of each species in each plot were measured for height and root collar diameter. In addition, 30 randomly selected seedling tops were severed from the roots, dried 24 h at 60°C, and ground to pass a 2-mm sieve. Whole-tissue (leaf and stem inclusive) subsamples were analyzed for total nitrogen (N) with a LECO-600® CHN analyzer.

### Statistical Analysis

The basic experiment represents a non-replicated, randomized block design for soil compaction (none and severe) and stump removal. ANOVA was used as the primary analysis technique and performed separately for each soil and seedling/species variable. Mean comparisons for soil and seedling growth parameters were calculated with Fisher's LSD. Accepted levels of significance were $P \leq 0.05$. Mean comparisons for ectomycorrhizae were also calculated using Fisher's LSD. Residuals from the ANOVAs were examined using stem-and-leaf plots or normal probability plots, tests that the residuals come from normal distributions, and plots of residuals versus predicted values. For Douglas-fir ectomycorrhizal numbers and types, the hypothesis that residuals came from a normal distribution was only rejected at a type I error rate of $P = 0.05$. The null hypothesis was not rejected for any other variable in Douglas-fir or western white pine.

## RESULTS AND DISCUSSION

### Soil

The untreated (no compaction) bulk density of this soil is very low (Table 1) as is common in fine-textured ash-cap soils of northern Idaho (Page-Dumroese 1993). As was expected, undisturbed soil bulk density on this ash-cap soil increased with depth. After the soil compaction treatment, soil bulk density increased at all sampling depths. These increases have persisted through three years of post-harvest measurements. Stump removal increased soil bulk density over pre-harvest measurements only at the 20–30 cm depth. However, in the surface soil, stump removal decreased bulk density due to soil mixing that takes place during stump pulling. The cone penetrometer also showed an increase in soil strength after stump removal near the 30-cm soil depth and reached a maximum at 40 and 45 cm. This was similar

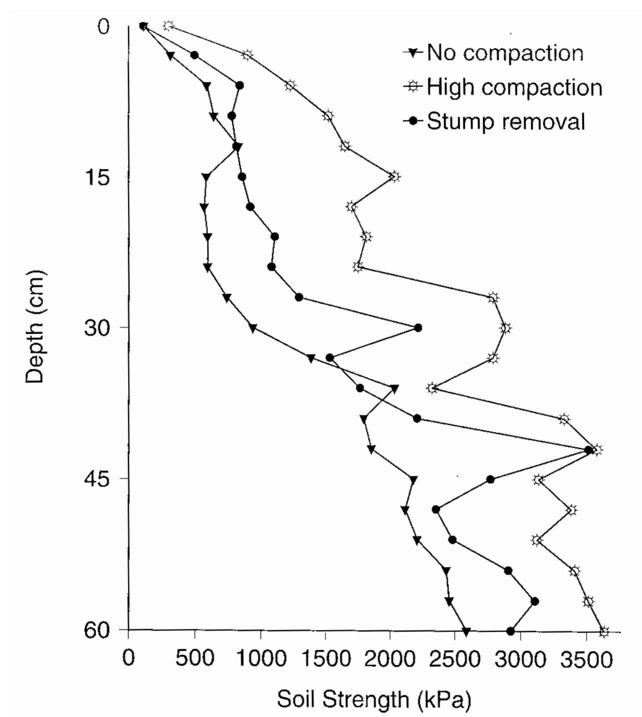


**Fig. 1**. Soil strength (kPa) as affected by severe compaction and stump removal. Standard error of the mean ±157.6.

to soil strength values obtained in the compacted treatment plot (Fig. 1).

The relative ease with which tracked vehicles compacted these low bulk density soils (four passes) serves as a reminder that low bulk density of ash-cap forest soils does not guard against compaction (Page-Dumroese 1993). Increased soil strength at the 40- to 45-cm depth after stump removal was most likely caused by equipment vibration at the surface. Volcanic ash surface horizons are considered nonplastic (Shoji et al. 1993) and appear particularly prone to vibrational compaction.

Other studies have evaluated the soil impacts of mechanical harvesting and stump removal activities in western North America. Stump removal with a D7 crawler tractor from a silt loam soil in British Columbia resulted in a 23%

**Table 2. Mean root and shoot weight and root volume of western white pine and Douglas-fir seedlings 1 yr after outplanting as affected by soil compaction or stump removal**

| Site treatment | Douglas-fir Root weight (g) | Douglas-fir Shoot weight (g) | Douglas-fir Root Volume (mL) | Western white pine Root weight (g) | Western white pine Shoot weight (g) | Western white pine Root Volume (mL) |
|---|---|---|---|---|---|---|
| No compaction | 5.5*a* | 12.6*a* | 25.6*a* | 8.1*a* | 17.9*a* | 27.3*a* |
| Soil compaction | 6.1*a* | 12.9*a* | 15.6*b* | 11.2*a* | 17.8*a* | 28.3*a* |
| Stump removal | 6.0*a* | 12.7*a* | 21.9*a* | 11.1*a* | 20.3*a* | 28.2*a* |

*a,b* In each column, different letters indicate significant differences ($P \leq 0.05$) by Fisher's LSD between treatments.

**Table 3. Height, root collar diameter, and seedling N content of western white pine and Douglas-fir seedlings 3 yr after outplanting as affected by soil compaction or stump removal**

| Site treatment | Douglas-fir Height (cm) | Douglas-fir Root Collar Diameter (mm) | Douglas-fir N (%) | Western white pine Height (cm) | Western white pine Root Collar Diameter (mm) | Western white pine N (%) |
|---|---|---|---|---|---|---|
| No compaction | 52.4*a* | 14.1*b* | 1.4*a* | 49.1*b* | 18.1*a* | 1.4*a* |
| Soil compaction | 51.7*ab* | 15.5*a* | 1.4*a* | 52.3*a* | 15.3*b* | 1.6*a* |
| Stump removal | 43.2*b* | 10.9*c* | 1.0*b* | 51.1*b* | 16.2*b* | 0.9*b* |

*a,b* In each column, different letters indicate significant differences ($P \leq 0.05$) by Fisher's LSD between treatments.

**Table 4. Ectomycorrhizal (EM) short roots, non-ectomycorrhizal (NEM) short roots, and number of ectomycorrhizal morphological types found on western white pine and Douglas-fir seedlings 1 yr after outplanting as affected by soil compaction or stump removal**

| Site treatment | Douglas-fir EM tips | Douglas-fir NEM tips | Douglas-fir Morphological types | Western white pine EM tips | Western white pine NEM tips | Western white pine Morphological types |
|---|---|---|---|---|---|---|
| No compaction | 70*a* | 50*a* | 3*a* | 85*a* | 77*a* | 4*a* |
| Soil compaction | 62*a* | 15*b* | 1*b* | 82*a* | 28*b* | 3*a* |
| Stump removal | 21*b* | 10*b* | 1*b* | 131*a* | 17*c* | 4*a* |

*a–c* In each column, different letters indicate significant differences ($P \leq 0.05$) by Fisher's LSD between treatments.

increase in bulk density and a 68% increase in soil strength in the top 20 cm of the gouge tracks (compacted area after stump removal) as compared to undisturbed soil (Smith and Wass 1994). Skid trails in volcanic ash soils had 26% higher bulk densities than undisturbed sites 25–32 yr after harvesting (Froehlich et al. 1985). Overall, compaction recovery rates of volcanic soil are slower than coarse-textured soils (Cullen et al. 1991) and are particularly slow at lower (>20 cm) depths (Geist et al. 1989). It is doubtful that deep soil compaction on fine-textured volcanic ash soils will be ameliorated within a rotation (Froehlich 1979).

## Seedling Growth

Douglas-fir, 1 yr after outplanting, had larger root volumes in the uncompacted plots as compared with compacted plots (Table 2). Shoot and root weight of Douglas-fir and western white pine were generally unaffected by compaction or stump removal. Western white pine root volumes were unaffected. Smaller rooting volumes for Douglas-fir seedlings in the compacted plots may be caused by a change in root morphology from many long, slender roots to fewer short, thick roots.

Douglas-fir seedlings grown 3 yr in the stump removal plot had a 20% reduction in height and a 30% reduction in root collar diameter compared with the other treatments (Table 3). Compaction did not seem to affect Douglas-fir aboveground characteristics. Western white pine seedlings showed mixed results. In the stump removal and soil compaction treatments, western white pine had 10% smaller root collar diameter than the no compaction treatment. However, 3-yr-old western white pine seedlings were tallest after soil compaction. In addition, seedling N content significantly declined in both species after stump removal as compared with the other treatments.

Numerous studies (e.g. Minore et al. 1969; Singer 1981; Heilman 1981) suggest that seedling top growth is less sensitive than root growth as an indicator of soil disturbance at least in the short-term. Soil in both the soil compaction and stump removal treatments exceeded 2500 kPa, the dry soil strength at which root growth is physically impeded (Greacen and Sands 1980; Nambiar and Sands 1992). Douglas-fir seedlings growing in the soil compaction treatment had large reductions in root volume. Lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.) seedlings grown for 13 wk in soil compacted to a soil strength of 2500 kPa had decreased new root growth and needle length (Conlin and van den Driessche 1996). After stump removal on non-volcanic ash soils in British Columbia, Douglas-fir and lodgepole pine seedlings planted in gouge tracks generally developed root systems inferior to seedlings growing on undisturbed ground or in deposited soil (Wass and Smith 1994). Root development was limited by high soil density or by high soil pH associated with subsoil horizons on the surface. Declines of seedling N after stump removal found in this study may become more pronounced as seedlings get older and demand for N increases (Sutton 1993).

## Ectomycorrhizae and Root Tips

Ectomycorrhizal development of 1-yr-old Douglas-fir seedlings was adversely reduced by stump removal (Table 4). Douglas-fir was much more sensitive than western white pine, with the former showing a 70% reduction in numbers of ectomycorrhizal root tips (compared to no compaction). However, both Douglas-fir and western white pine had significant decreases in the number of non-ectomycorrhizal root tips after compaction or stump removal. Similarly, Douglas-fir showed substantial reductions (63% of no compaction treatments) in the numbers of ectomycorrhizal morphological types supported in the soil compaction and stump removal treatments. The number of morphological types on western white pine seedlings was similar regardless of treatment.

The strong, negative relationship of ectomycorrhizal number and diversity on Douglas-fir seedlings planted in soil compaction and stump removal treatments underscores the risk of planting this species in heavily disturbed soils. Not only is Douglas-fir susceptible to *Armillaria*, it is also vulnerable to the potentially negative effects of reduced populations and diversity of important root symbionts (Harvey et al. 1994). Healthy forests typically have diverse ectomycorrhizal flora (Arnolds 1991; Eberhardt et al. 1996), but little information on the impacts of reducing ectomycorrhizal diversity on seedling growth is available. Reduction of nonmycorrhizal root tips for both Douglas-fir and western white pine after site treatment is likely a result of soil density and structure changes and may have affected both seedling species ability to uptake N. Declines in ectomycorrhizae and nonmycorrhizal roots decreases the seedlings' ability to capture site resources and can adversely affect reforestation success (Amaranthus and Perry 1987, 1989a, 1989b).

## Management Implications

Intensive site disturbance activity, with associated soil compaction and mixing, may decrease site productivity by altering the soil physical environment directly, or indirectly from disturbance-related changes in the abundance and species composition of soil microorganisms. Productivity losses caused by soil disturbance are difficult to predict, but results of this study suggest that compaction and churning from logging activities and stump removal can adversely affect belowground seedling ectomycorrhizae and nonmycorrhizal roots. In addition, the loss of organic matter from heavy disturbance decreases nutrient retention (Cullen et al. 1991; Page-Dumroese et al. 1991). Use of seedling species more tolerant of root diseases may be needed to enhance regeneration, rather than relying on stump removal or other methods of physical disturbance to rid a site of disease problems (Harvey et al. 1994).

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